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Behaviour of geosynthetic-reinforced soil retaining wall subjected to forced cyclic horizontal displacement at wall face

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ABSTRACT: Forced cyclic lateral displacements took place at the wall by thermal expansion/contraction of RC facing of a 11 m-high U-shape soil retaining wall due to daily and seasonal changes of the temperature, which resulted into large residual lateral displacements toward the active side of the wall due to the increment in the residual earth pressure as well as large settlement in the backfill behind the wall facing. A set of small-scale model tests was performed in the laboratory. It was found that these detrimental effects can be removed by reinforcing the backfill with polymer geogrid layers that are connected to the back face of thin RC facing.

1 INTRODUCTION

An about 11 m-high steel-reinforced U-shaped retaining wall with sand backfill (Figure 1) exhibited a gradual increment in the residual lateral earth pressure, which resulted in an outward displacement (i.e., toward the active side) at the wall top equal to 18 cm (for the two walls at the opposite sides) in about three years after its completion with a danger of structural damage (Sumiyoshi, 2005). Correspondingly, the crest of the backfill settled down about 2 cm at a distance of about 10 m from the facing with the settlement increasing at places closer to the facing. It was considered that this phenomenon is due to "a ratcheting phenomenon (described latter in Figure 3)" in the earth pressure caused by cyclic lateral displacements of the RC facing caused by daily or seasonal changes in the temperature. Ng et al. (1998), for example, showed that a similar phenomenon takes place with the abutments of integrated bridges. Figure 2 shows the time-histories of lateral displacement measured at the top of the wall for the two walls (at point X in Fig. 1) and the temperature in the surrounding air and their relations during one day and for about two years. An *in-situ* investigation (Sumiyoshi, 2005) and laboratory model loading tests (Nojiri et al., 2005) revealed the following with respect of the mechanism of the increment in the earth pressure and the development of residual lateral displacement of the facing:

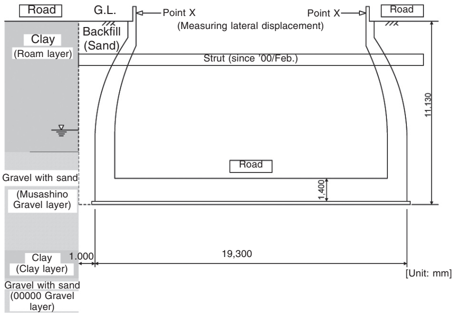


Figure 1. Cross-section of the RC U-shaped soil retaining wall (Sumiyoshi, 2005)

(1) The RC facing moves outward (i.e., toward the active side) by contraction of the surface zone of the facing relative to the deeper zone closer to the backfill when the temperature drops, which results in outward displacement and settlement of the active zone in the backfill (Figure 3b).
(2) On the other hand, the RC facing moves inward (i.e., toward the passive side) by expansion of the surface zone of the facing when the temperature rises. However, the active zone cannot return to the original location, resulting into the increment in the lateral earth pressure (Figure 3c).
(3) By repeating mechanisms (1) & (2) above, the backfill becomes stiffer while residual displacement towards the active side of the facing tends to be accumulated if it is allowed.
(4) The peak value of earth pressure in each cycle (i.e., the passive earth pressure) exhibits a gradual

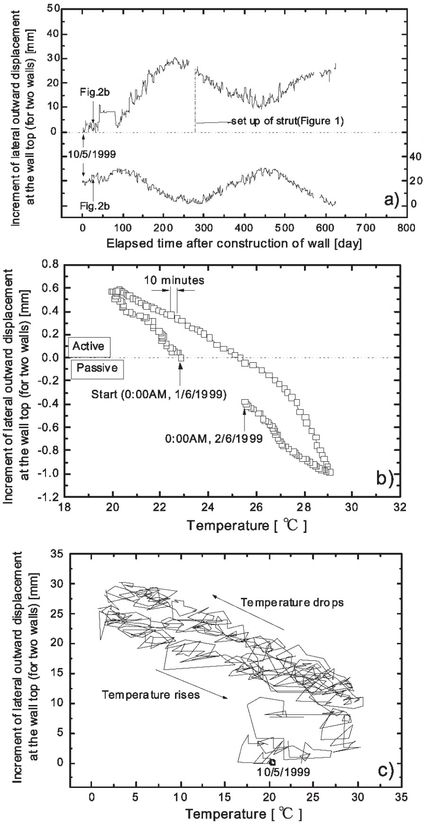
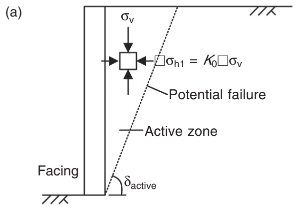


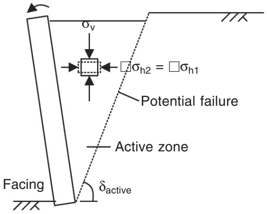
Figure 2. (a) Time-histories of lateral displacement at the wall top at point X in Fig.1 (for two walls) and temperature in the surrounding air; and their relations during (b) a single day & (c) for about two years (Sumiyoshi, 2005).

increase with cyclic loading while the active zone exhibits a gradual settlement.

It was considered that the residual settlement in the backfill by forced cyclic lateral displacements of the facing can be substantially reduced by reinforcing the backfill with polymer geogrid layers that are connected to the back face of the facing. To validate the above, a series of model wall tests was performed in the present study.



(b) Overturning forward to active side caused by heat contraction due to decreasing of temperature



(c) Overturning forward to passive side caused by heat expansion due to decreasing of temperature

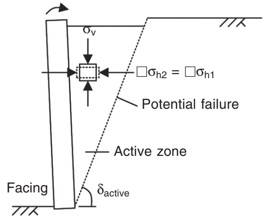


Figure 3. Ratcheting mechanism in the wall subjected to cyclic lateral displacements.

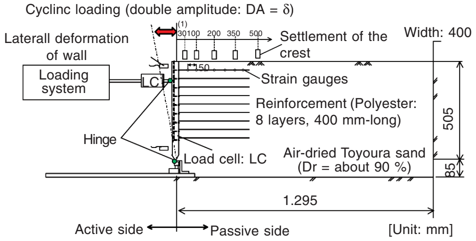


Figure 4. Model retaining wall with reinforced backfill.

2 EXPERIMENTAL SETUP

As shown in Figure 4, a 505 mm-high full-height rigid facing model, having at its back face nine two-component load cells to measure the distribution of vertical and horizontal loads, was placed on a hinge. The back face of the facing was made rough by gluing sandpaper #150. The facing was cyclically and laterally loading at 11.5 cm below the top of the facing via another hinge at a constant rate (0.004 mm/sec). The bottom hinge was the center of wall rotation. The ratio of the double amplitude of lateral displacement at the facing top to the wall height (δ/H) was equal to 0.2 or 0.6%. $\delta/H = 0.2\%$ was two times larger than the double amplitude of seasonal cyclic thermal displacement of the prototype wall (Fig. 1). Residual lateral displacements due to the increment in the earth pressure were not allowed to take place, assuming a very rigid wall system against the earth pressure increase.

Air-dried Toyoura sand, as the model backfill, was compacted by the tamping method to reach initial relative density D_r of about 90% (γ = about 1.60 g/cm^3). The backfill was either unreinforced or reinforced with eight layers of 40 cm long model grid reinforcement at a vertical spacing of 5 cm. The reinforcement consisted of 1 mm-wide polyester members coated with polyethylene for protection at a center-to-center spacing of 18 mm in both longitudinal and transverse directions. The tensile rupture strength at a strain rate of 1%/min was 18.6 kN/m. Local tensile strains in the top reinforcement layer were measured with seven electric-resistance strain gauges. The settlement on the crest of the backfill was measured as shown in Fig. 4.

3 TEST RESULTS AND DISCUSSIONS

Figure 5 shows the relationships between the total earth pressure coefficient, $K = 2Q/(\gamma H^2)$, and δ/H obtained from two tests in which the backfill was unreinforced and other two in which the backfill was reinforced. Here, Q is the total lateral earth pressure measured with the local load cells; and γ is the total unit weight of the backfill. The results from monotonic active and passive loading tests are also presented in Fig. 5a. The time histories of settlement at the crest measured at 3 cm from the back of the facing (point 1 in Fig. 4) and the peak value of K in each cycle, K_{peak}, are shown in Figures 6 & 7. The relationship between K_{peak} and the corresponding settlement at the crest of the backfill are shown in Figure 8.

The following trends of behaviour may be seen from these figures. When the backfill was unreinforced, the K_{peak} value gradually increased by cyclic loading to a larger extent for a larger δ/H. When the wall system is not rigid and strong enough, the wall may largely displaces toward the active side and serious structural damage may result. An active failure plane (i.e., a shear band) developed in the backfill at about 160 cycles when $\delta/H = 0.2\%$ and 7 cycles when $\delta/H = 0.6\%$. The direction of the failure planes was nearly the same as the one in the monotonic loading test toward the active side and independent of δ/H. Such a delayed development of active failure plane during cyclic loading as above can be attributed to the ratcheting mechanism (Fig. 3). Large settlement took place at the backfill crest behind the facing, which well corresponds to the field observation in the case of Fig. 1.

The initial earth pressure was very high because of the reinforcement layers were fixed to the model facing, when the backfill was reinforced. When a support to the facing was released after the construction by compaction of the backfill, the backfill did not yield towards the active side. The earth pressure increased by cyclic loading at a rate and toward values, both much higher when compared to those when the backfill was unreinforced. On the other hand, the settlement at the backfill crest became nearly zero despite the earth pressure increased largely. When $\delta/H = 0.6\%$, even the crest heaved when the wall was loaded toward the passive side.

The development of large earth pressure when the backfill was reinforced can be attributed to an increase in the lateral stiffness of the backfill due to an increased confining pressure associated with increased earth pressure. This high earth pressure was supported by the reinforcement layers. Figure 9 shows the

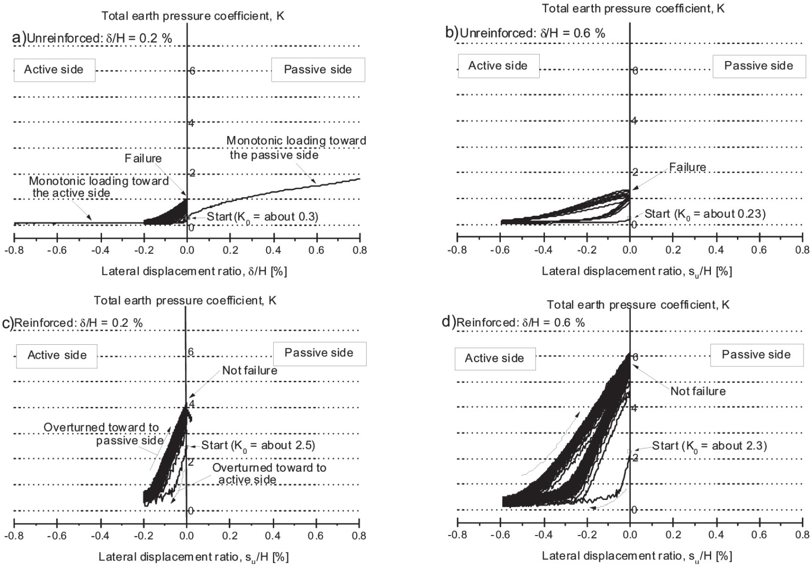


Figure 5. Relationships between K and δ/H (positive at the passive side): (a) & (b) unreinforced backfill; and (c) & (d) geosynthetics-reinforced backfill: loading started first toward the active side.

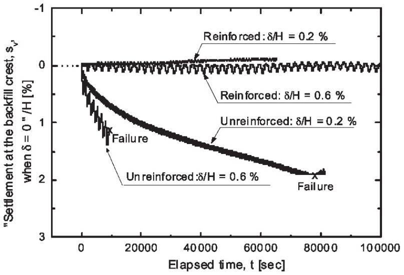


Figure 6. Time-histories of settlement at the backfill crest (3 cm from the back of facing).

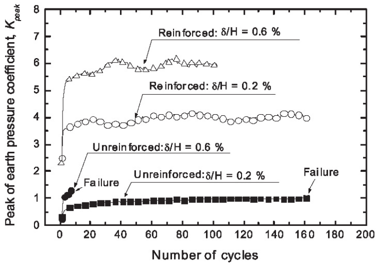


Figure 7. The peak value of K in each cycle, K_{peak}.

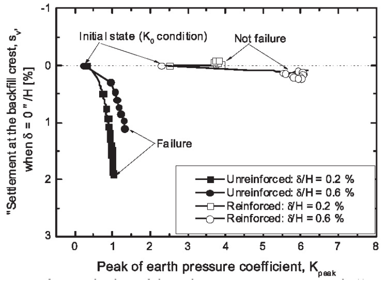


Figure 8. Relationships between K_{peak} and "s_v when d = 0" /H.

relationships between the tensile strain along the top reinforcement layer (measured 10 cm from the back face of the facing) and *δ/H*.

It should be noted that, for a given lateral load applied to the wall facing, the lateral displacement of the facing when the backfill is reinforced is much smaller than that when the backfill is unreinforced due to an increased lateral stiffness of the backfill by reinforcing. So, under those different conditions, the behaviour of the wall with reinforced backfill for a certain value of *δ/H* should be compared with the one with unreinforced backfill for a much larger *δ/H*. Moreover, when the backfill is reinforced, the facing is lateral supported with a number of reinforcement layers at a small span, which results in least structural damage by increased earth pressure.

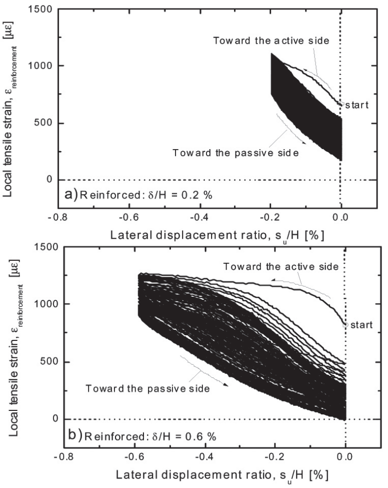


Figure 9. Relationships between local tensile strain of reinforcement (positive in tension) and d/H (positive at the passive side): (a) d/H = 0.2 %, and (b) d/H = 0.6 %.

4 SUMMARY

Forced cyclic lateral displacements at the wall face took place by thermal expansion/contraction of U-shaped RC wall due to daily or seasonal temperature changes. Similar cyclic lateral displacements of wall can take place with the abutments of integrated bridges. The detrimental effects by such cyclic loading as above include excessive outward wall displacements, structural damage to the facing due to increased earth pressure and settlement of the backfill behind the wall face. The results from the present study showed that these detrimental effects can be effectively removed by reinforcing the backfill with geosynthetic layers connected to the back of the facing.

REFERENCES

Ng, C., Springman, S. and Norrish, A. (1998), "Soil-structure interaction of spread-base integral bridge abutments", Soils and Foundations, Vol. 38, No. 1, pp. 145-162.

Nojiri, M., Kasahara, T., Hirakawa, D., Tastuoka, F., Sumiyoshi, T., Uchimura, T. and Arai, T. (2005), "Residual deformation and earth pressure of reraining wall subjected to multiple horizontal cyclic loading", Proceedings of 40th Japan National Conference on Geotechnical Engineering, Hakodate, pp. 1753-1754 (in Japanese).

Sumiyoshi, T. (2005). "Behaviour of U-type Retaining Wall subjected to cyclic displacement", Annual report of Institute of Civil Engineering of Tokyo Metropolitan Government 2005 (in Japanese).